EXHIBIT B

US 20080030592A1

(19) **United States**
(12) **Patent Application Publication**
(10) **Pub. No.: US 2008/0030592 A1**
(43) **Pub. Date: Feb. 7, 2008**

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(54) **PRODUCING DIGITAL IMAGE WITH DIFFERENT RESOLUTION PORTIONS**

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(21) Appl. No.: **11/461,574**

(22) Filed: **Aug. 1, 2006**

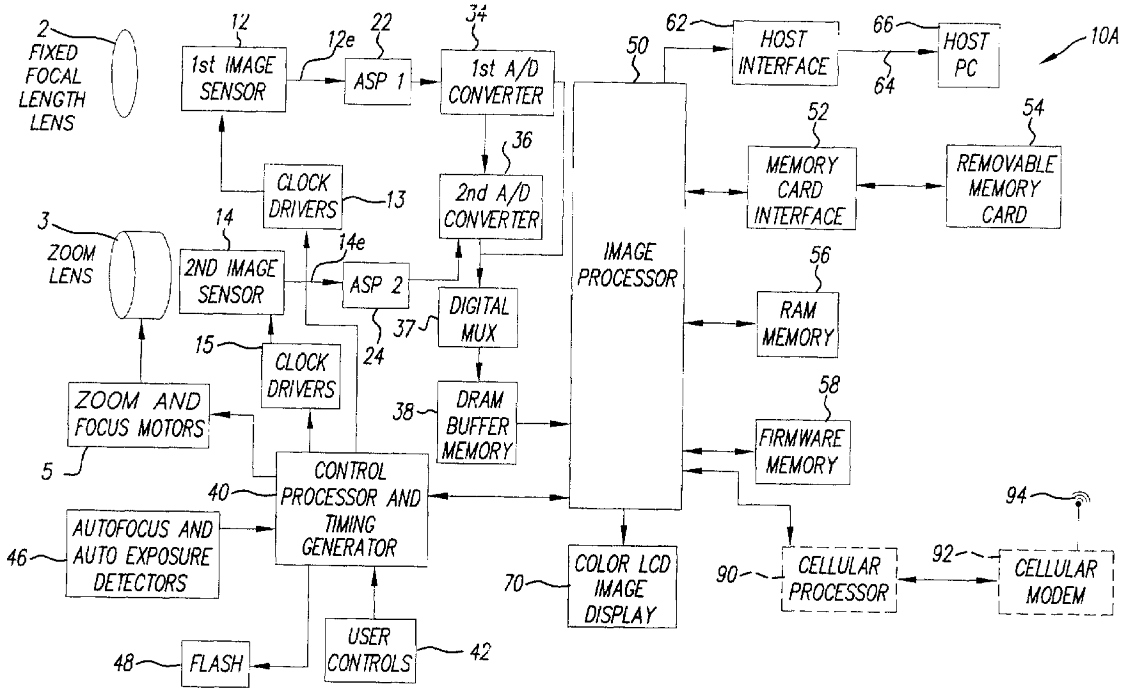
Publication Classification

(51) **Int. Cl.**
G06T 5/50 (2006.01)

(52) **U.S. Cl.** **348/218.1**; 348/E05.028

(57) **ABSTRACT**

A method of producing a digital image with improved resolution during digital zooming, including simultaneously capturing a first low resolution digital image of a scene and a second higher resolution digital image of a portion of substantially the same scene. A composite image is then formed by combining the first low-resolution digital image and a corresponding portion of the high resolution digital image. Digital zooming of the composite image produces a zoomed image with high resolution throughout the zoom range and improved image quality.



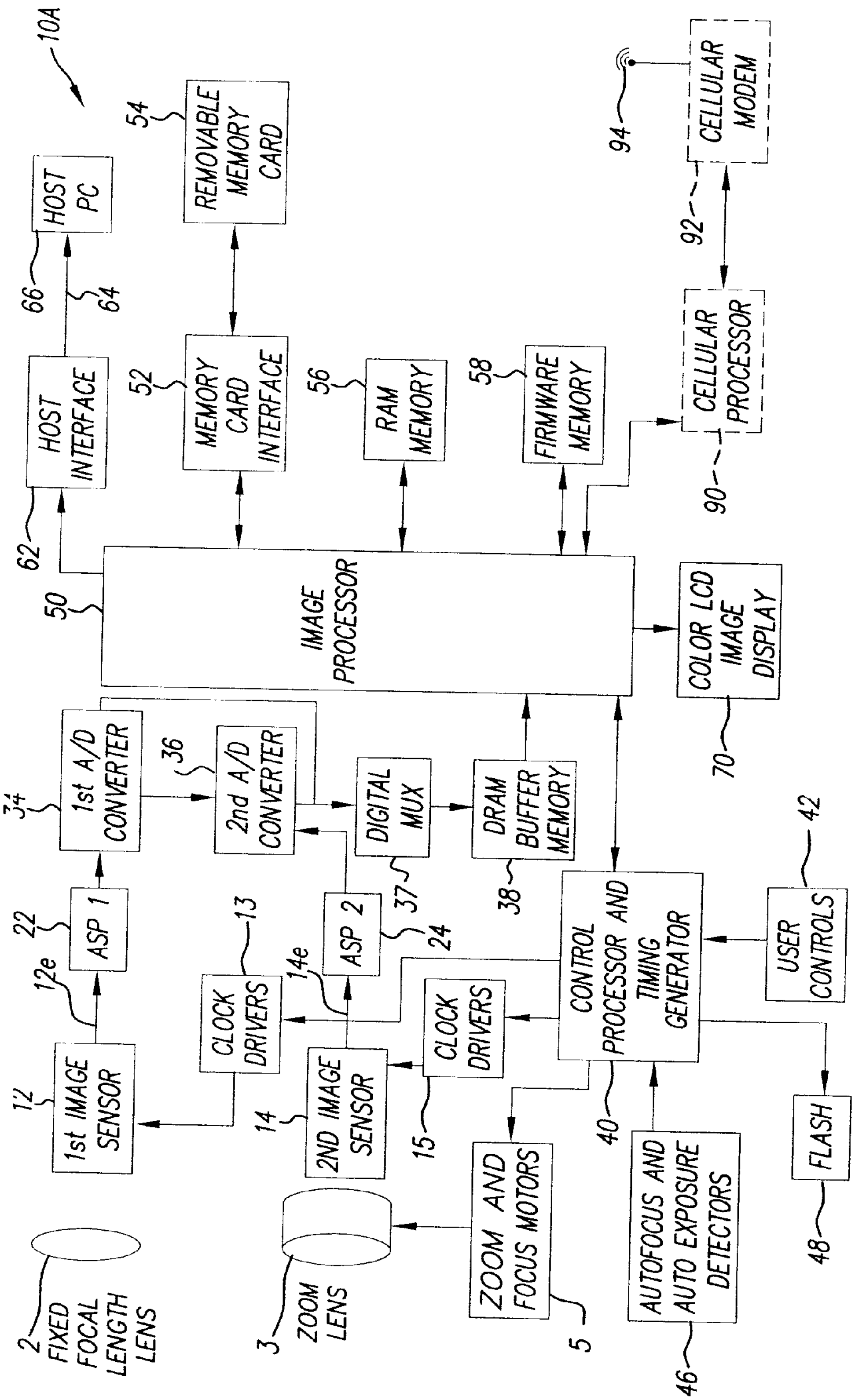

10A
2 FIXED FOCAL LENGTH LENS
3 ZOOM LENS
5 ZOOM AND FOCUS MOTORS
12 1st IMAGE SENSOR
12e
13 CLOCK DRIVERS
14 2ND IMAGE SENSOR
14e
15 CLOCK DRIVERS
22 ASP 1
24 ASP 2
34 1st A/D CONVERTER
36 2nd A/D CONVERTER
37 DIGITAL MUX
38 DRAM BUFFER MEMORY
40 CONTROL PROCESSOR AND TIMING GENERATOR
42 USER CONTROLS
46 AUTOFOCUS AND AUTO EXPOSURE DETECTORS
48 FLASH
50 IMAGE PROCESSOR
52 MEMORY CARD INTERFACE
54 REMOVABLE MEMORY CARD
56 RAM MEMORY
58 FIRMWARE MEMORY
62 HOST INTERFACE
64
66 HOST PC
70 COLOR LCD IMAGE DISPLAY
90 CELLULAR PROCESSOR
92 CELLULAR MODEM
94

FIG. 1A

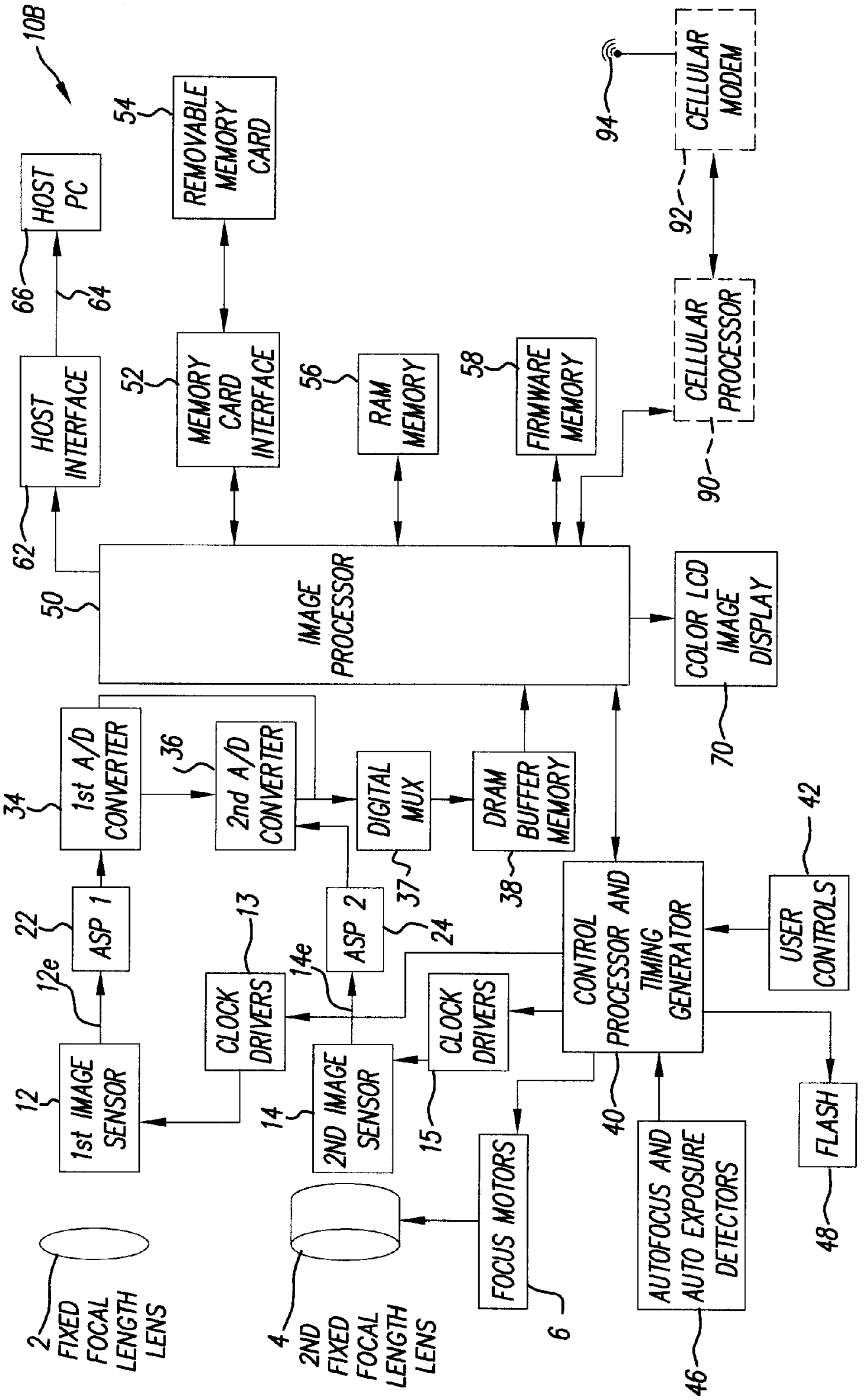

10B
HOST PC
66
64
REMOVABLE MEMORY CARD
54
CELLULAR MODEM
94
92
HOST INTERFACE
62
MEMORY CARD INTERFACE
52
RAM MEMORY
56
FIRMWARE MEMORY
58
CELLULAR PROCESSOR
90
IMAGE PROCESSOR
50
COLOR LCD IMAGE DISPLAY
70
1st A/D CONVERTER
34
2nd A/D CONVERTER
36
DIGITAL MUX
37
DRAM BUFFER MEMORY
38
ASP 1
22
ASP 2
24
12e
14e
CLOCK DRIVERS
13
CLOCK DRIVERS
15
CONTROL PROCESSOR AND TIMING GENERATOR
40
USER CONTROLS
42
1st IMAGE SENSOR
12
2ND IMAGE SENSOR
14
FOCUS MOTORS
6
AUTOFOCUS AND AUTO EXPOSURE DETECTORS
46
FLASH
48
2 FIXED FOCAL LENGTH LENS
4 2ND FIXED FOCAL LENGTH LENS

FIG. 1B

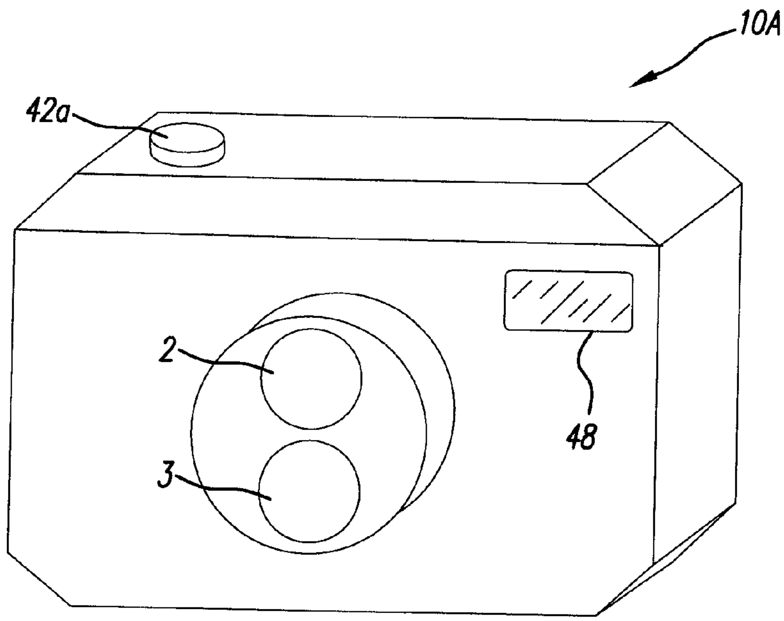


FIG. 2A

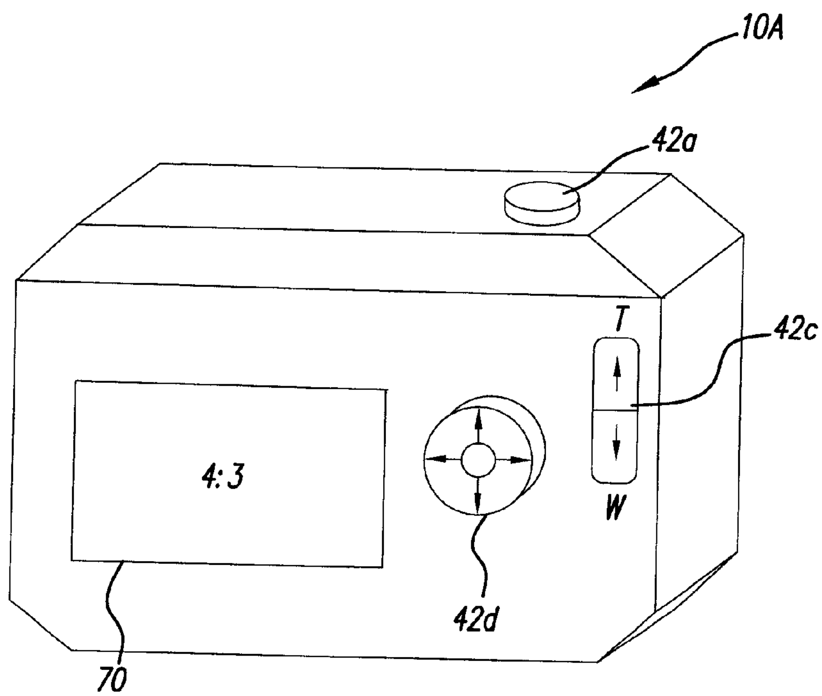


FIG. 2B

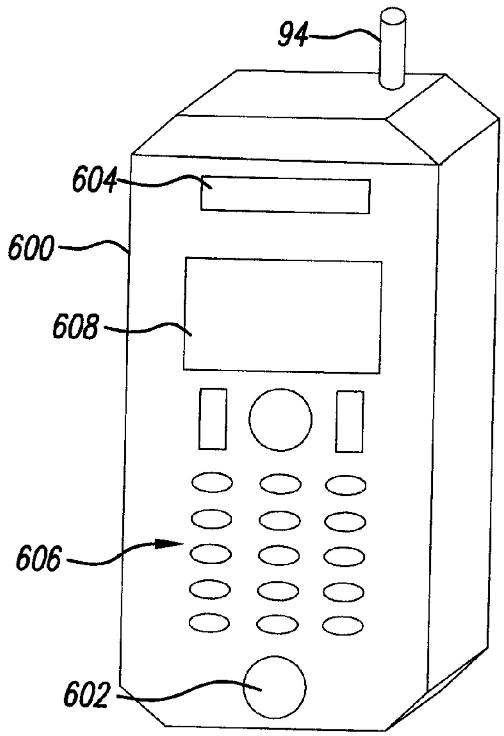

94
604
600
608
606
602

FIG. 3A

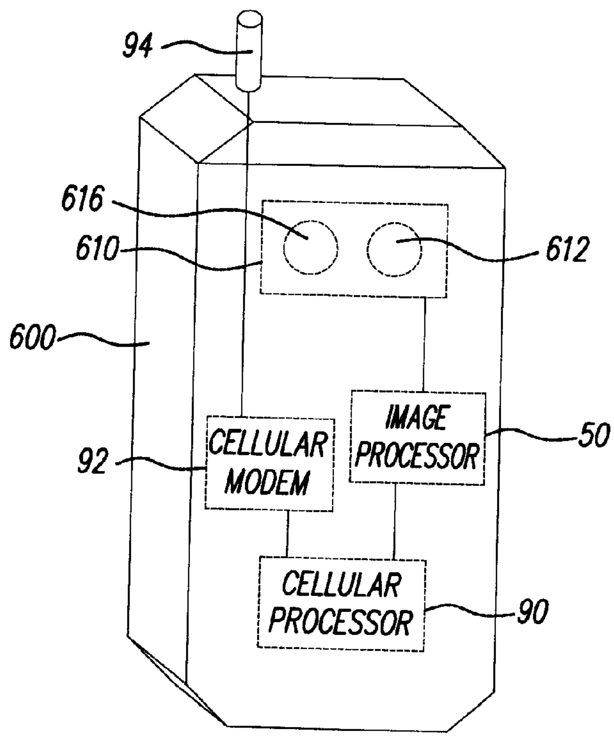

94
616
610
612
600
IMAGE PROCESSOR
50
92
CELLULAR MODEM
CELLULAR PROCESSOR
90

FIG. 3B

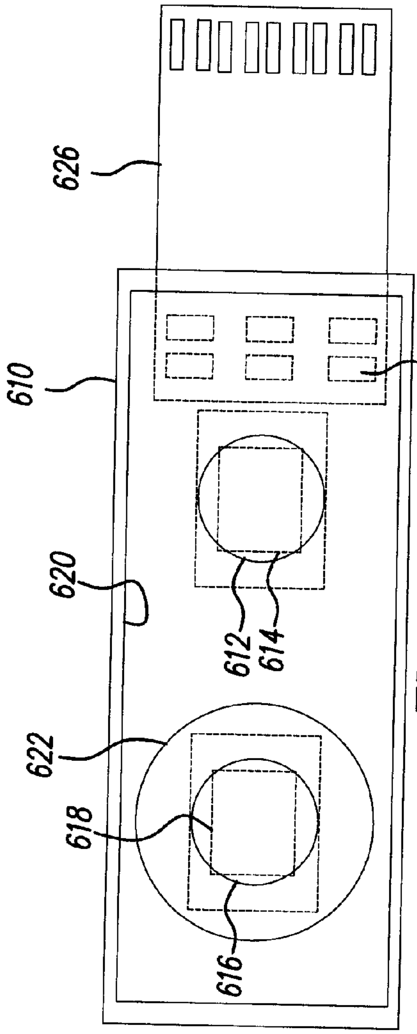

626
610
624
620
612
614
622
618
616

FIG. 4A

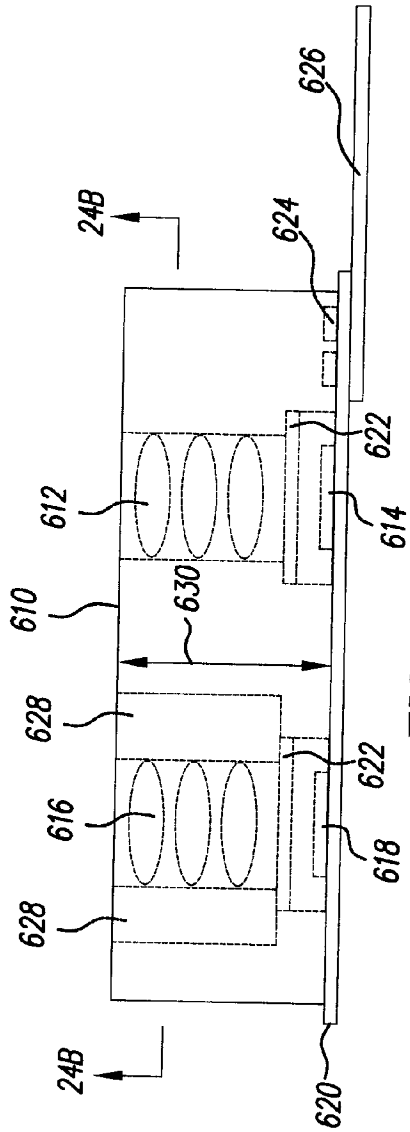

626
24B
624
622
612
614
610
630
628
616
618
620

FIG. 4B

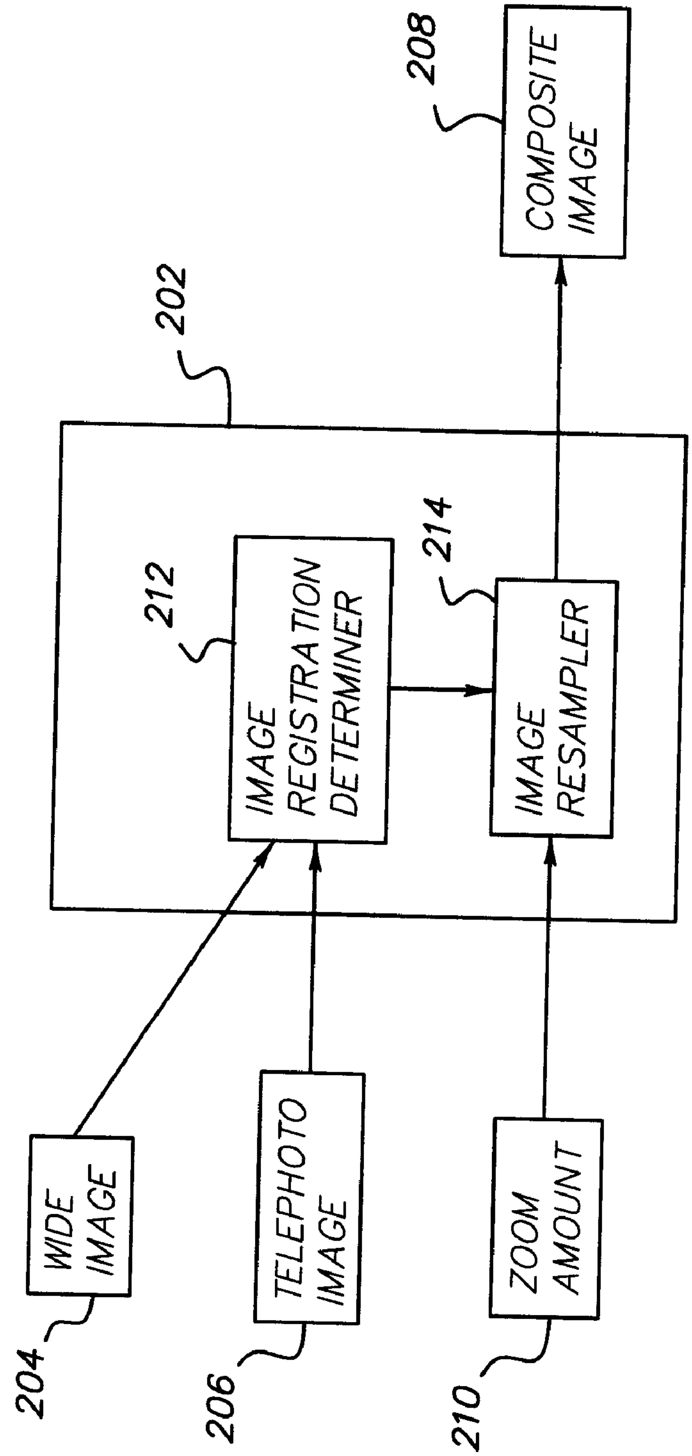

208
COMPOSITE IMAGE
202
212
IMAGE REGISTRATION DETERMINER
214
IMAGE RESAMPLER
WIDE IMAGE
204
TELEPHOTO IMAGE
206
ZOOM AMOUNT
210

FIG. 5

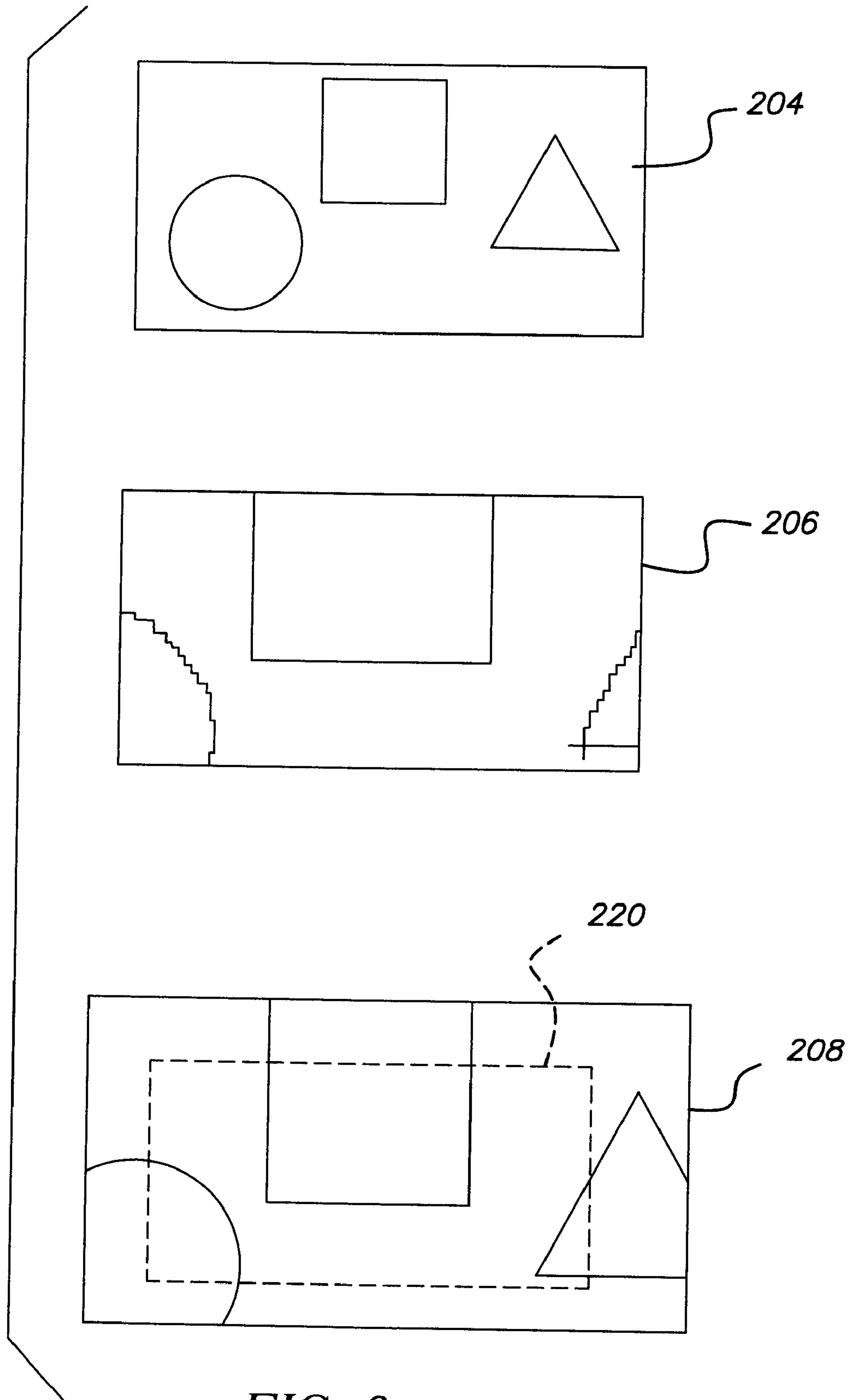


FIG. 6

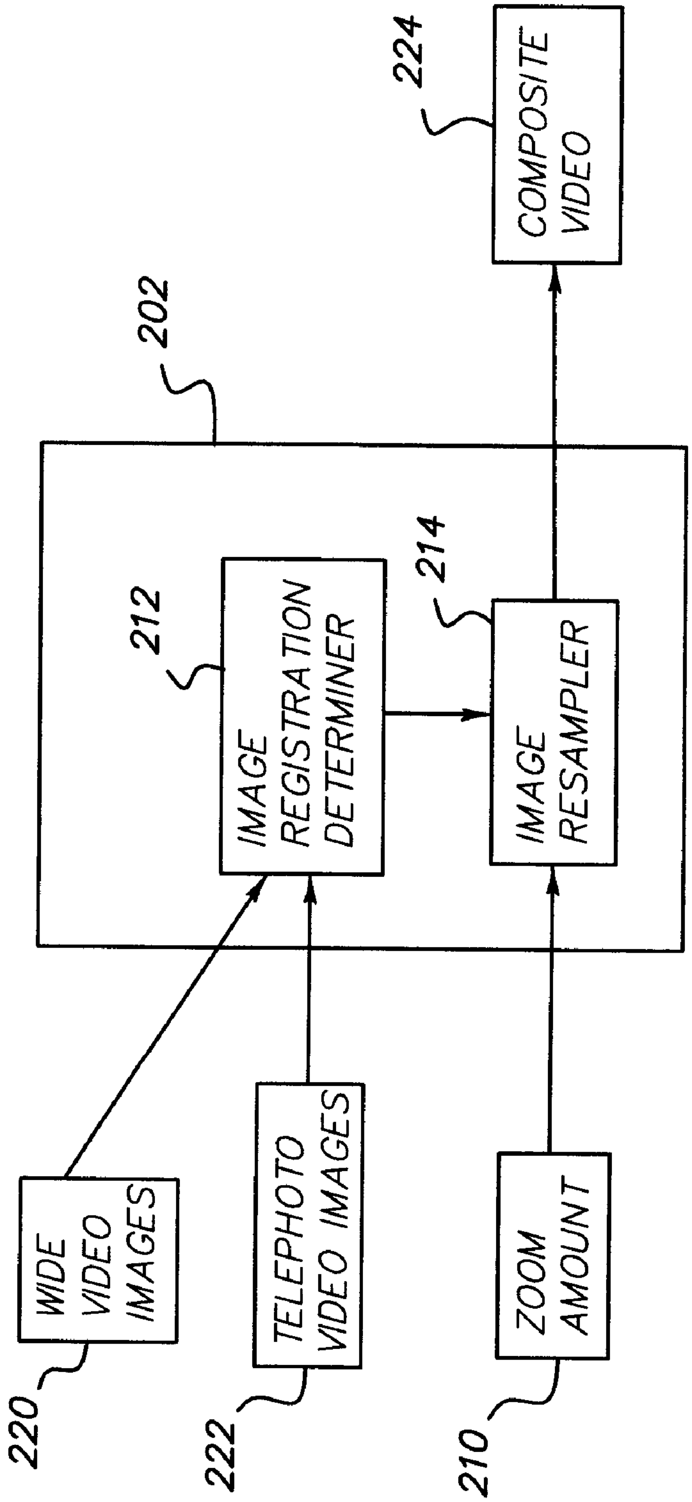

224
COMPOSITE VIDEO
202
212
IMAGE REGISTRATION DETERMINER
214
IMAGE RESAMPLER
WIDE VIDEO IMAGES
220
TELEPHOTO VIDEO IMAGES
222
ZOOM AMOUNT
210

FIG. 7

PRODUCING DIGITAL IMAGE WITH DIFFERENT RESOLUTION PORTIONS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Reference is made to commonly assigned U.S. Patent Application Serial No. 2002/0075258, filed Nov. 23, 2001, entitled "Camera System with High Resolution Image Inside a Wide Angle View" by Park et al. and U.S. patent application Ser. No. 11/062,174, filed Feb. 18, 2005, entitled "Digital Camera Using Multiple Lenses And Image Sensors To Provide An Extended Zoom Range" by Peter Labaziewicz, et al., the disclosures of which are incorporated herein.

FIELD OF THE INVENTION

[0002] The present invention relates to a digital camera that uses multiple lenses and image sensors to provide an extended zoom range and the method used to produce a digital image that combines the multiple images produced by the digital camera.

BACKGROUND OF THE INVENTION

[0003] Currently, most digital cameras use a zoom lens and a single color image sensor to capture still and motion images. The captured images are then digitally processed to produce digital image files, which are stored in a digital memory in the camera. The digital image files can then be transferred to a computer, displayed, and shared via the Internet. The digital camera can be included as part of a mobile telephone, to form a so-called "camera phone." The camera phone can transmit the digital image files to another camera phone, or to service providers, via a mobile telephone network.

[0004] Small camera size and a large zoom range are two very important features of digital cameras. Users prefer to have a large zoom range (e.g. 5:1 or greater) rather than a limited zoom range (e.g. 3:1 or smaller). The zoom range is typically composed of both optical zoom which is provided by variable focal length lenses and digital zoom which is provided by a magnification of the digital image after capture. Variable focal length lenses for large zoom range are expensive and they increase the size of the digital camera. Thus, there are trade-off's between small camera size, large zoom range, and low camera cost which must be made when designing a digital camera. With higher cost cameras, such as single lens reflex cameras, these problems are sometimes addressed by using multiple interchangeable zoom lenses, such as two 3:1 zoom lenses, e.g., a 28-70 mm zoom and a 70-210 zoom. This arrangement has user inconvenience problems and is presently not available for low cost digital cameras.

[0005] A different solution that has been offered by Kodak in the V570 and the V610 cameras is to include two different lens assemblies in the camera with two different focal lengths and two separate image sensors. In this case, each of the lens assemblies can be either a fixed focal length lens or can have a moderate optical zoom range to reduce the size and cost of each of the lens assemblies. Together, the two lens assemblies provide a wide zoom range and a small overall size at a lower cost. However, a problem arises when the focal length of the first lens does not match the focal length of the second lens so that the optical zoom is not continuous over the entire zoom range. In this case, digital zoom must be used for zoom between the maximum zoom of the first lens and the minimum zoom of the second lens.

[0006] Digital zoom based on increased magnification of the image with a corresponding decrease in resolution is well known in the art. Although digital zoom is very fast and simple, the decrease in resolution can produce a perceived decrease in image quality.

[0007] In U.S. Pat. No. 5,657,402, a method is described in which a plurality of digital images are combined to form an image. U.S. Pat. No. 5,657,402 addresses the use of multiple images captured at different times wherein "the plurality of images of various focal lengths, such as a zoom video sequence" (col. 1, lines, 21-22) are captured from the same lens. U.S. Pat. No. 5,657,402 does not address two lens assemblies simultaneously capturing images of the same scene.

[0008] In US Publication No. 2002/0075258, a panoramic camera system is described in which a moveable telephoto camera is additionally used to capture a high-resolution portion of the scene which is then overlaid onto the panoramic image. US Publication No. 2002/0075258 describes the use of a moveable telephoto camera to enable a higher resolution of a portion of the image wherein the moveable telephoto camera can be moved to the region of the panoramic image where the higher resolution is desired. US Publication No. 2002/0075258 does not address the case wherein a wide-angle camera and a telephoto camera are affixed together for simultaneous capture of the same scene. In addition, US Publication No. 2002/0075258 does not disclose the use of a composite image for improved image quality in a digital zoom system.

SUMMARY OF THE INVENTION

[0009] The present invention provides a sufficiently compact, low cost, optical system with a large zoom range for a small, lightweight and relatively inexpensive consumer digital camera.

[0010] What is therefore needed is a digital camera that provides a rapidly-operating extended zoom range without unduly increasing the size or cost of the digital camera while providing good perceived image quality throughout the zoom range.

[0011] An object of the invention is to provide a method of producing a digital image having portions with different resolutions comprising:

[0012] a. simultaneously capturing first and second digital images of the same scene wherein the first digital image is of a larger portion of the scene than the second digital image wherein the second digital image has a higher resolution than the resolution in the first digital image corresponding to the second digital image; and

[0013] b. combining at least a portion of the second digital image into the corresponding portion of the first digital image to thereby provide a digital image having portions with different resolutions.

[0014] The present invention is directed to overcoming the problems set forth above. Briefly summarized, the invention includes an electronic camera for producing an image of a scene, wherein the camera includes a first image sensor for generating a first sensor output, a first lens with a first focal length for forming a first image of the scene on the first image sensor, a second image sensor for generating a second sensor output, and a second lens with a second focal length

that is longer than the focal length of the first lens for forming a second image of the same scene on the second image sensor. The first lens or the second lens can be either fixed focal length lenses or multiple focal length lenses as in a zoom lens wherein, the first and second lenses are directed at substantially the same scene and image sets are captured substantially simultaneously by the first image sensor and the second image sensor. Portions of the image set captured by the first image sensor and the second image sensor are then combined to produce a composite image with a higher resolution in the portion of the composite image that is provided by the second image sensor due to the longer focal length of the second lens. Subsequent images produced during a digital zooming process are composed largely of the lower resolution image captured by the first image sensor at low digital zoom values and largely of the higher resolution image as captured by the second image sensor at high digital zoom values.

[0015] By forming a composite image with portions of the image from the short focal length lens and portions of the image from the longer focal length lens, perceived image quality is improved throughout the zoom range while lens complexity is reduced, since a continuous zoom ratio can be produced with unmatched lens focal lengths. By capturing images from the two image sensors substantially simultaneously, complexities in the image processing are reduced since differences between the two images due to motion of the camera or motion within the scene are avoided. It is an additional advantage, that the present invention can avoid the slow response that is typical of an optical zoom system when traversing a large zoom range.

[0016] These and other aspects, objects, features and advantages of the present invention will be more clearly understood and appreciated from a review of the following detailed description of the preferred embodiments and appended claims, and by reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIGS. **1**A and **1**B depict a block diagram of a digital camera using a fixed focal length wide-angle lens with a first image sensor and a zoom lens, or a longer second fixed focal length lens, with a second image sensor according to the present invention;

[0018] FIGS. **2**A and **2**B show front and rear perspective views of the digital camera;

[0019] FIGS. **3**A and **3**B are perspective views of the front and back of a cell phone including a camera with multiple lenses and multiple sensors according to the present invention;

[0020] FIGS. **4**A and **4**B show two views of the capture assembly used in the cell phone shown in FIGS. **3**A and **3**B

[0021] FIG. **5** is a block diagram of the stitching process to create the composite image;

[0022] FIG. **6** depicts a wide angle image as captured, a telephoto image as captured, and a composite image as created by the invention; and

[0023] FIG. **7** is a block diagram of the stitching process with video images to create a composite video.

DETAILED DESCRIPTION OF THE INVENTION

[0024] Because digital cameras employing imaging devices and related circuitry for signal capture, correction, and exposure control are well known, the present description will be directed in particular to elements forming part of, or cooperating more directly with, method and apparatus in accordance with the present invention. Elements not specifically shown or described herein are selected from those known in the art. Certain aspects of the embodiments to be described are provided in software. Given the system as shown and described according to the invention in the following materials, software not specifically shown, described or suggested herein that is useful for implementation of the invention is conventional and within the ordinary skill in such arts.

[0025] In the image capture device that is the subject of the invention, two or more lens systems are associated with a respective number of image sensors. The lenses have different focal lengths and different fields of view within the same scene wherein the field of view of the longer focal length lenses contains at least a portion of the field of view of the shorter focal length lens. In addition, the image captured by the image sensor associated with the longer focal length lens has a higher resolution than the image captured by the image sensor associated with the lens with the shorter focal length.

[0026] In the embodiment of the invention, the image capture done by the two or more image sensors is done substantially simultaneously so that motion artifacts from motion of the camera or motion within the scene, do not cause differences in the two or more images that are captured. The invention discloses the use of the two or more images to form a composite image that includes portions of each of the two or more images for the purpose of providing a digitally zoomed image with uniformly high resolution.

[0027] Each of the several embodiments of the present invention include an image capture assembly having multiple lenses and multiple image sensors mounted within a digital camera wherein the multiple lenses have different focal lengths and portions of the fields of view are substantially the same and the multiple image sensors can capture images simultaneously. The invention describes an arrangement for producing an image that is formed by combining the images from the multiple image sensors in a way that provides increased resolution in a digitally zoomed image.

[0028] In each embodiment, the camera captures images from the multiple image sensors simultaneously. Each multiple lens system contains at least one fixed focal length lens or variable focal length lens as in an optical zoom lens. Moreover, each embodiment includes some type of user control that allows a user to select a zoom amount, which controls both the digital zoom and the optical zoom lens if present. In some embodiments, a single “zoom lens” user control is used. e.g., where the “wide” setting selects a wide angle fixed focal length lens and the “tele” setting(s) select various positions of a zoom lens. In any case, digital zooming is used along with any optical zoom that is present to provide a continuous zoom “up” from the image obtained with the short focal length lens to the maximum focal length of the multiple lenses. All this, of course, can be transparent

to the user, who simply manipulates the "zoom" user control between the "wide" and "tele" settings.

[0029] The composite image can be formed during image processing on the camera or later during post processing when the images have been offloaded from the camera. In either case, the two images must be matched to locate the high-resolution image accurately into the low-resolution image and then stitched into place so the edge between the two images in the composite image is not discernible. To enable the composite image to be formed during post processing, both images in the image set must be stored at the time of image capture. In the case of video, by storing the low-resolution video and the high resolution video, the zoom ratio can be selected after image capture and adjusted as desired at that time.

[0030] Turning now to FIG. **1**A, a digital camera **10**A is described which includes an image capture assembly, including a fixed focal length lens **2** that focuses an image of a scene (not shown) onto a first image sensor **12**, and a zoom lens **3** which focuses an image of the scene onto a second image sensor **14**. The image capture assembly **1** provides a first image output signal **12***e* from the first image sensor **12** and a second image output signal **14***e* from the second image sensor **14**.

[0031] The focal length of the fixed focal length lens **2** generates a wide-angle field of view and has a fixed focus set to a distance near the lens hyperfocal distance of 8 feet so that objects from 4 feet to infinity are in focus. Therefore, the fixed focal length lens **2** does not need to include a focus adjustment. The fixed focal length lens **2** includes an adjustable aperture and shutter assembly to control the exposure of the first image sensor **12**. The zoom lens **3** includes an optical zoom and autofocus controlled by zoom and focus motors **5** and an adjustable aperture and shutter assembly to control the exposure of the image sensor.

[0032] In a preferred embodiment, the image sensors **12** and **14** are single-chip color Megapixel CCD sensors, using the well-known Bayer color filter pattern to capture color images. The image sensors **12** and **14** can have, for example, a 4:3 image aspect ratio and a total of 3.1 effective megapixels (million pixels), with 2048 active columns of pixels× 1536 active rows of pixels. The image sensors **12** and **14** can use a ½" type optical format, so that each pixel is approximately 3.1 microns tall by 3.1 microns wide. A control processor and timing generator **40** controls the first image sensor **12** by supplying signals to clock drivers **13**, and controls the second image sensor **14** by supplying signals to clock drivers **15**.

[0033] The control processor and timing generator **40** also controls the zoom and focus motors **5** for zoom lens **3**, and a flash **48** for emitting light to illuminate the scene. The control processor and timing generator **40** also receives signals from automatic focus and automatic exposure detectors **46**. In an alternative embodiment, instead of using the automatic focus and automatic exposure detectors **46**, the image sensor **14** could be used to provide exposure detection and "through-the-lens" autofocus, as described in commonly-assigned U.S. Pat. No. 5,668.597 entitled "Electronic Camera with Rapid Automatic Focus of an Image upon a Progressive Scan Image Sensor" which issued Sep. 26, 1997 in the names of Kenneth A. Parulski, Masaki Izumi, Seiichi Mizukoshi and Nobuyuki Mori, incorporated herein by reference. User controls **42** are used to control the operation of the digital camera **10**A.

[0034] The first image output signal **12***e* from the first image sensor **12** is amplified by a first analog signal processor (ASP **1**) **22** and provided to a first analog-to-digital (A/D) converter **34**. The second image output signal **14***e* from the second image sensor **14** is amplified by a second analog signal processor (ASP **2**) **24** and provided to a second A/D converter **36**.

[0035] The digital data from the A/D converters **34** and **36** is provided to digital multiplexer **37**. The digital multiplexer **37** is used to select which one of the outputs of the two A/D converters **34** and **36** is connected to the DRAM buffer memory **38**. The digital data is stored in DRAM buffer memory **38** and subsequently processed by an image processor **50**. The processing performed by the image processor **50** is controlled by firmware stored in fin-ware memory **58**, which can be flash EPROM memory. The image processor **50** processes the input digital image file, which is buffered in a RAM memory **56** during the processing stage. The image processor **50** combines the digital data from the A/D converters **34** and **36** to form a composite image with areas of high resolution and areas of lower resolution using a method, which constitutes the invention.

[0036] As shown in FIG. **5**, the image processor **50** of FIGS. **1**A and **1**B contains an image compositor **202** that receives both the wide image **204** from the fixed focal length lens **2** and the telephoto image **206** from the zoom lens **3**. The telephoto image **206** is of a smaller portion of the scene than the wide image **204**, but captures this smaller portion with greater resolution than the resolution of the wide image **204**. The image compositor **202** generates a composite image **208** using image data from both the wide image **204** and the telephoto image **206**. Also, the image compositor **202** receives a zoom amount **210** that can be adjusted by the camera user as will be described below.

[0037] It is desirable for the image compositor **202** to generate a composite image **208** that has the highest possible quality. For illustration, assume that the wide image **204** and the telephoto image **206** have the same number of rows R and columns C of pixels, for example, R=1000 and C=1500 and that the relative magnification ratio M of the telephoto image **206** to the wide image **204** is M=3.

[0038] The image registration determiner **212** determines the registration between the wide image **204** and the telephoto image **206**. The coordinate transformation is simply a translation and a scale because the image sensors that capture the wide image **204** and the telephoto image **206** are coplanar. A convenient way to represent the registration between the images is to find the mapping of the four corner pixels of the telephoto image **206** onto the wide image **204**. For example,

Telephoto Image Coordinates	Wide Image Coordinates
(0, 0)	(333, 499.7)
(999, 0)	(666, 499.7)
(0, 1499)	(333, 999.3)
(999, 1499)	(666, 999.3)

The registration can also be stored in the form of the homography H_{TW} that transforms the coordinates of the telephoto image **206** to the wide image **204**.

[0039]

$$\begin{bmatrix} x_w \\ y_w \\ 1 \end{bmatrix} = H_{TW} \begin{bmatrix} x_T \\ y_T \\ 1 \end{bmatrix}$$

Where coordinates of the telephoto image **206** are in (row, column) notation (y_T, x_T) and coordinates of the wide image **204** are (y_W, x_W). For example,

[0040]

$$H_{TW} = \begin{bmatrix} 1/M & 0 & 499.7 \\ 0 & 1/M & 333 \\ 0 & 0 & 1 \end{bmatrix}$$

[0041] The correspondences between the coordinate systems represent the registration between the wide image **204** and the telephoto image **206**. The correspondences are preferably determined at the time of manufacture by shooting test targets, as is well known in the art. If one or both of the lenses were a zoom lens rather than a fixed lens., the registration correspondences could still be determined at the time of manufacture as a function of the zoom position of the lenses. It should be further noted that while the example shows a pure translate and scale transformation, it may be necessary to correct for a difference in tilt between the two imaging systems.

[0042] Alternatively, the registration between images can be determined using the image information contained in the wide image **204** and telephoto image **204**. This is well known in the art of image processing (for example, image registration is described in U.S. Pat. No. 6,078,701) and generally includes the steps of finding interest points in each image, making guesses at corresponding points (i.e. a scene feature that appears in both images), determining an initial guess at the registration, using that initial guess to refine the correspondence point guess, and so on based on comparing pixel values or contrast in the two images.

[0043] The image resampler **214** uses the registration information and the zoom amount **210** to produce the composite image **208**. Preferably, the composite image has the same number of rows and columns of pixels as the wide image **204** and the telephoto image **206**. However, it is well known to those skilled in the art that modifying the number of rows and columns of pixels (interpolating the image) can easily be done so that the image contains the desired number of pixels.

[0044] The zoom amount **210** Z specifies the desired relative zoom amount of the produced composite image **208**. Preferably, when the value of Z=1, then the composite image is the wide image **204**. On the other hand, when Z-M, then the composite image **208** is the telephoto image **206**. When the zoom amount is between 1 and M, data from both the wide image **204** and the telephoto image **206** are used by the image resampler **214** to produce the composite image **208**.

[0045] The image resampler **214** applies the zoom amount Z as follows: Each pixel position (y_c, x_c) of the composite image **208** is mapped to the coordinates of wide image **204** according to:

$$\begin{bmatrix} x_W \\ y_W \\ 1 \end{bmatrix} = H_{CW} \begin{bmatrix} x_C \\ y_C \\ 1 \end{bmatrix}$$

where

$$H_{CW} = \begin{bmatrix} 1/Z & 0 & (1-M)(C-1) \\ 0 & 1/Z & (1-M)(C-1) \\ 0 & 0 & 1 \end{bmatrix}$$

In a similar manner, the position (y_c, x_c) of the composite image **208** is mapped to the coordinates of the telephoto image **206** using the equation:

$$\begin{bmatrix} x_T \\ y_T \\ 1 \end{bmatrix} = (H_{TW})^{-1} H_{CW} \begin{bmatrix} x_C \\ y_C \\ 1 \end{bmatrix}$$

Then, the pixel value of the composite image at position (y_c, x_c) is found by interpolation. If the mapped position of (y_c, x_c) in the telephoto image **206** lands within the limits of the existing pixels (i.e. $0<=x_T<=C-1$), the pixel value of the composite image **208** at position (y_c, x_c) is found by interpolating pixel values of the telephoto image **206**. Otherwise, the pixel value of the composite image **208** at position (y_c, x_c) is found by interpolating pixel values of the wide image **204**.

[0046] Those skilled in the art will recognize that the above description of producing the values of the composite image **208** using pixel values of the wide image **204** and the telephoto image **206** can be accomplished in many ways. For example, it is easy to pre-calculate the region of pixel locations of the composite image **208** for which the pixel values will be produced by interpolating the telephoto image **206** and the region for which the pixel values will be produced by interpolating the wide image **204**. This saves computational cost but produces the same image data.

[0047] FIG. **6** shows an example set of images. The wide image **204** covers a wide portion of the scene and the telephoto image **206** covers a smaller portion of the scene, but with greater resolution. The produced composite image **208** uses pixel data from the telephoto image **206** for those portions (i.e. the region within the dashed line **220**) that are in the view of the telephoto image **206** and uses pixel data from the wide image **204** otherwise (i.e. the region outside the dashed line **220**). The dashed line **220** shows where the transition is. Thus, the composite image **208** has higher resolution in the interior and lower resolution on the edges. Since the subject of a photograph, especially in consumer photography, is likely to be near the center of the scene, the subject of the composite image **208** is likely to have the highest resolution. It has also been experimentally determined that the transition within the composite image **208** between pixels derived by interpolating the wide image **204** versus the telephoto image **206** does not product visually objectionable artifacts.

[0048] Since lenses **2** and **3** are separated by some distance, it is possible that objects very close to the camera will appear to have a discontinuity at the transition. In this case, it is possible to use standard image processing techniques to

find objects that are close to the camera and to process these regions in a fashion that does not produce a discontinuity artifact. For example, the pixel values of the composite image **208**, for objects that are close to the camera and span the transition region, can be determined by interpolating the wide image **204**. A true depth map can also be created and used by the image resampler **214** to sample the appropriate locations within the telephoto image **206** and the wide image **204**. In this case, the registration model is no longer a simple scale translation model.

[0049] A further feature of the present invention is that the composite image **208** can be stored on the camera without digital zooming. Therefore, digital zooming of the composite image **208** can be (lone later, during post processing, to create an image for use by the operator for printing or sharing. The composite image **208** can be formed during image processing on the camera or later during post processing when the images have been offloaded from the camera. To enable the composite image to be formed during post processing, the wide image **204** and the telephoto image **206** must both be stored at the time of image capture.

[0050] The invention can also be applied to a series of sequential images as in a video. Referring to FIG. **7**, in the case of video, two sets of video images, wide video images **220** and telephoto video images **222** are captured substantially simultaneously from the two lenses **2** and **3** or **2** and **4** and the two image sensors **12** and **14** providing video images from a short focal length lens **2** and a zoom lens **3** or a longer second focal length lens **4**. The composite video **224** is formed by combining the two sets of video images **220** and **222**. The composite video **224** can be formed during image processing on the camera and stored on the camera or the composite video **224** can be formed later during post processing when the images have been offloaded from the camera. To enable the composite video **224** to be formed during post processing, the wide video images **220** from the short focal length lens **2** and the telephoto video images **222** from the zoom lens **3** or the longer focal length lens **4** must both be stored at the time of image capture. Digital zoom of the video images can be accomplished on the camera during capture, or on the camera after capture, or during post processing after the composite video **224** has been offloaded from the camera or during post processing when the composite video **224** is being formed.

[0051] The processed digital image file is provided to a memory card interface **52**, which stores the digital image file on the removable memory card **54**. Removable memory cards **54** are one type of removable digital image storage medium, and are available in several different physical formats. For example, the removable memory card **54** can include (without limitation) memory cards adapted to well-known formats, such as the Compact Flash, SmartMedia. MemoryStick, MMC, SD, or XD memory card formats. Other types of removable digital image storage media, such as magnetic hard drives, magnetic tape, or optical disks, can alternatively be used to store the still and motion digital images. Alternatively, the digital camera **10**A can use internal non-volatile memory (not shown), such as internal flash EPROM memory to store the processed digital image files. In such an embodiment, the memory card interface **52** and the removable memory card **54** are not needed.

[0052] The image processor **50** performs various image processing functions, including color interpolation followed by color and tone correction, in order to produce rendered sRGB image data. The rendered sRGB image data is then JPEG compressed and stored as a JPEG image file on the removable memory card **54**. The rendered sRGB image data can also be provided to a host PC **66** via a host interface **62** communicating over a suitable interconnection, such as a SCSI connection, a USB connection or a Firewire connection. The JPEG file uses the so-called "Exif" image format defined in "Digital Still Camera Image File Format (Exit)" version 2.1, July 1998 by the Japan Electronics Industries Development Association (JEIDA), Tokyo, Japan. This format includes an Exif application segment that stores particular image metadata, including the date or time the image was captured, as well as the lens f/number and other camera settings.

[0053] It should be noted that the image processor **50**, although typically a programmable image processor, can alternatively be a hard-wired custom integrated circuit (IC) processor, a general purpose microprocessor, or a combination of hard-wired custom IC and programmable processors.

[0054] The image processor **50** also creates a low-resolution "thumbnail" size image, which can be created as described in commonly-assigned U.S. Pat. No. 5,164,831, entitled "Electronic Still Camera Providing Multi-Format Storage Of Full And Reduced Resolution Images" issued in the name of Kuchta, et al., the disclosure of which is herein incorporated by reference. After images are captured, they can be quickly reviewed on a color LCD image display **70** by using the thumbnail image data. The graphical user interface displayed on the color LCD image display **70** is controlled by the user controls **42**.

[0055] In some embodiments of the present invention, the digital camera **10**A is included as part of a camera phone. In such embodiments, the image processor **50** also interfaces to a cellular processor **90**, which uses a cellular modem **92** to transmit digital images to a cellular network (not shown) using radio frequency transmissions via an antenna **94**. In some embodiments of the present invention, the image capture assembly **1** can be an integrated assembly including the lenses **2** and **3**, the image sensors **12** and **14**, and zoom and focus motors **5**. In addition, the clock drivers **13** and **15**, as well as the analog signal processors **22** and **24**, the digital multiplexer **37**, and the A/D converters **34** and **36**, can be part of the integrated assembly.

[0056] FIGS. **2**A and **2**B show perspective views of the digital camera **10**A and **10**B described in relation to FIGS. **1**A and **1**B respectively. FIG. **2**A is a front view of the digital camera **10**A, showing the fixed focal length lens **2**, and the zoom lens **3** and flash **48**. The fixed focal length lens **2** is preferably a very short focal length lens so that the camera can be very thin. Other lens focal lengths and lens type constructions are within the scope of the invention.

[0057] FIG. **2**B is a rear view of the digital camera **10**A. The various operator controls for the user interface are shown as **42***a*, **42***c* and **42***d*. The display for viewing the images is shown as **70**. The aspect ratio of the display is typically 4:3 but can be any other ratio.

[0058] In a further preferred embodiment, as shown in FIG. **1**B, digital camera **10**B includes an adjustable focal lens system with two fixed focal length lenses **2** and **4**, each providing an image to a corresponding image sensor **12** and **14**. The digital camera **10**B is capable of simultaneous image capture on both image sensors **12** and **14**. The two fixed focus lenses are selected to provide a substantial zoom range, for example, 3:1 wherein the focal length of the

second fixed focal length lens **4** is 3× as long as the fixed focal length lens **2**. As in digital camera **10**A, a composite image is constructed from the two images captured on images sensors **12** and **14**. Digital zoom is applied to the composite image between the image captured with the short fixed focal length lens **2** on first image sensor **12** and the image captured with the longer second fixed focal length lens **4** on second image sensor **14**. The zoom control **42***c* can provide zoom settings over the zoom range, for example, from 1 to 3. The remaining aspects of the digital camera **10**B are similar to the digital camera **10**A shown in FIG. **1**A, and retain the same reference characters. Reference is therefore made to FIG. **1**B for further description of these aspects of the digital cameras **10**B.

[0059] A number of advantages can be obtained by use of the fixed focal length lenses in digital camera **10**B. The aperture of each lens can be kept quite large (e.g., f/2.8 at least for the widest angle lens), thereby providing a high speed, low light lens. In addition, the image quality of the optical assembly can be kept higher and at a lower manufacturing cost than for a comparable zoom lens. When digital zooming is employed, there are no moving parts for the zoom—even though there are multiple zoom settings—and the zoom is completely silent and relatively fast in zoom focal length transitions. In addition, the overall size of the image module including both fixed focus lenses and both image sensors is very compact which makes this embodiment important for cell phone cameras and other applications in which size is critical.

[0060] In many of the foregoing embodiments, digital zooming is used. Digital zooming is a well-known process and can be constructed using a variety of techniques. One such digital zooming capability is described in commonly-assigned pending U.S. Patent Application Publication No. 2003/0202113, "Electronic Still Camera and Image Processing Method" filed on Aug. 1, 2002 in the name of Sumito Yoshikawa and which is incorporated herein by reference. For the type of system disclosed in this pending patent application, as well as for the system according to the present invention, the image sensor includes an array of discrete light sensitive picture elements overlaid with a color filter array (CFA) pattern to produce color image data corresponding to the CFA pattern. The output data from the image sensor is applied to an analog signal processing (ASP) and analog/digital (A/D) conversion section, which produces digital CFA data from the color image data.

[0061] The resultant digital data is applied to a digital signal processor, such as the image processor **50** (referring to FIGS. **1**A and **1**B of the present invention), which interpolates red, green, and blue (RGB) color image data for all of the pixels of the color image sensor. The CFA image data represents an image of a fixed size, such as 2048 columns of pixels×1536 rows of pixels. A digitally zoomed image is created by taking the center section of the CFA image data and interpolating any additional pixels that fall in between the pixels provided by the image sensor. For example, a 2:1 digital zoom is provided by using only the center 1024 columns×768 rows of the CFA image data and interpolating one additional row and column in between each of the rows and columns of the center CFA image data so as to enlarge the center of the image. The output of the image processor **50** is a color interpolated and digitally zoomed image, with 2048 columns and 1536 rows of RGB data, provided from the center 1024 columns×768 rows of CFA image data.

[0062] To operate the present imaging system according to the teaching of the aforementioned Yoshikawa patent, the user operates the digital camera, e.g., the digital camera **10**A or **10**B, to take pictures while observing the image on the color LCD image display **70**. The digital CFA image for each of the captured images is processed by the image processor **50** and displayed in a "thumbnail" or subsampled format in the preview step. If the observed zoom amount is not desired, the user then changes the zooming/cropping setting in a zoom selection or cropping step by using the zoom button **42***c*. For example, a 2.5:1 overall zoom setting can be provided by using the center 1638 columns×1230 rows from the 2048 columns×1536 rows of CFA image data. The composite image will then contain more columns and rows of image data in the central area where the image captured with the longer focal length lens is located.

[0063] In a preferred embodiment, the image produced on the color LCD image display (**70**) is derived from the composite image containing data from both the wide image and the telephoto image. In an alternative embodiment, the image on the color LCD image display can be derived entirely from the wide image to reduce the computational requirements for producing the LCD image.

[0064] Multiple lenses and multiple sensors, and the use of an integrated image capture assembly, can be adapted for use in a cell phone of the type having a picture taking capability. Accordingly, and as shown in FIG. **3**A, a cell phone **600** includes a phone stage comprising a microphone **602** for capturing the voice of a caller, related electronics (not shown) for processing the voice signals of the caller and the person called, and a speaker **604** for reproducing the voice of the person called. A keypad **606** is provided for entering phone numbers and image capture commands and a (LCD) display **608** is provided for showing phone-related data and for reproducing images captured by the phone or received over the cellular network. The rear view of the cell phone **600** shown in FIG. **3**B identifies some of the internal components, including a cellular image capture assembly **610** connected via the image processor **50** (as shown in FIGS. **1**A and **1**B) to a cellular processing stage comprising the cellular processor **90** and the cellular modem **92**. The cellular processor **90** receives and processes the image data from the image processor **50** and the voice data captured by the microphone **602**, and transfers the image and voice data to the cellular modem **92**. The cellular modem **92** converts the digital image and voice data into the appropriate format for transmission by the antenna **94** to a cellular network.

[0065] The cellular image capture assembly **610** as shown in FIGS. **4**A and **4**B, where FIG. **4**B is a top view of the cellular image capture assembly **610** taken along the lines **24**B-**24**B in FIG. **4**A, comprises an integrated packaging of the optical and imaging components on a common substrate **620**. More specifically, the cellular image capture assembly **610** includes a first fixed focal length lens **612** and a first image sensor **614**, and a second fixed focal length lens **616** and a second image sensor **618**. The first fixed focal length lens **612**, preferably a fixed focal length wide angle lens, forms an image on the first image sensor **614**, and the second fixed focal length lens **616**, preferably a fixed focal length telephoto lens with a longer focal length, forms an image on the second image sensor **618**. Both of the lenses are oriented

in the same direction in order to form images of the same portion of the overall scene in front of them, but different fields of view.

[0066] Each fixed focal length lens **612** and **616** and each associated image sensor **614** and **618** are mounted to the substrate **620** with an IR cut filter **622** in between to reduce the incidence of IR radiation on the image pixels. Electronic components **624**, such as resistors, capacitors and power management components, are also mounted on the substrate **620**. A flex connector **626** is used to take the image data from the substrate **620**. The data can be raw image data or, if suitable processors (not shown) are on board the substrate **620**, YUV image data or JPEG image data. Moreover, the image processor **50** can provide digital zooming between the wide angle and the telephoto focal lengths; the user can initiate such zooming via a user interface displayed on the (LCD) display **608** and by keying appropriate buttons on the keypad **606**. Furthermore, the wide-angle image sensor **614** can have high resolution, e.g., higher than that of the telephoto second image sensor **618**, in order to provide a higher quality source image for the digital zooming.

[0067] In one embodiment, the wide angle first fixed focal length lens **612** is set to its hyperfocal distance, which means it is in focus from a few feet to infinity without need for any focus adjustment by the user. The telephoto second fixed focal length lens **616** is automatically focused by an auto focus subsystem **628** because the hyperfocal distance increases as the focal length increases requiring that the focus be adjusted in order to obtain proper focus for objects at typical (e.g. 4' to 12') distances. By using only one focusing subsystem **628** for the telephoto second fixed focal length lens **616**, the cost and size can be reduced.

[0068] In this embodiment the "z" dimension **630** can be reduced consistent with cell phone layout and architecture. Careful choice of the telephoto focal length, the use of a folded optical path and the size of the sensor can further reduce the "z" dimension **630**. For example, the size of the second image sensor **618**, and consequently the size of the image that must be produced to fill the sensor, can be made small enough to reduce the focal length to an acceptable "z" dimension **630**.

[0069] Although not shown in detail in FIGS. **4**A and **4**B, but similarly, as was explained in connection with FIG. **3**, an analog output signal from the first image sensor **614** is amplified by a first analog signal processor and provided to a first A/D converter to produce the first digital image data. The first digital image data is provided to the digital multiplexer and the DRAM buffer memory. Similarly, the analog output signal from the second image sensor **618** is amplified by a second analog signal processor and converted to a second digital image data by a second A/D converter. The second digital image data is then provided to the digital multiplexer and the DRAM buffer memory. The first digital image data and the second digital image data are both provided to an input of the image processor wherein the composite image is formed by combining portions of the two images. Wherein the A/D converters, the digital multiplexer, the DRAM buffer memory, and the image processor are provided as electronic components **624** on the substrate **620**. The digital zooming of the composite image is done in accordance with the setting of the zoom control.

[0070] It is a feature of the invention that by simultaneously capturing two images, of the same scene but different fields of view and different resolutions, a composite image can be formed without having to account for camera motion or motion within the scene. In the case of photographing objects in a scene that are positioned near the camera, adjustments will have to be made for parallax when the two lenses are separated by a substantial distance. This issue will only surface when objects in the scene are very near to the camera. However, in a further preferred embodiment, the two lenses will share a common optical axis to avoid parallax issues between the two images.

[0071] The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

[0072] **2** fixed focal length lens
[0073] **3** zoom lens
[0074] **4** second fixed focal length lens
[0075] **5** zoom and focus motors
[0076] **6** focus motors
[0077] **10**A digital camera (first embodiment)
[0078] **10**B digital camera (second embodiment)
[0079] **12** first image sensor
[0080] **12***e* first image output signal
[0081] **13** clock drivers
[0082] **14** second image sensor
[0083] **14***e* second image output signal
[0084] **15** clock drivers
[0085] **22** first analog signal processor (ASP**1**)
[0086] **24** second analog signal processor (ASP**2**)
[0087] **34** first A/D converter
[0088] **36** second A/D converter
[0089] **37** digital multiplexer
[0090] **38** DRAM buffer memory
[0091] **40** control processor and timing generator
[0092] **42** user controls
[0093] **42***a* shutter button
[0094] **42***c* zoom button
[0095] **42***d* multi-position selector
[0096] **46** automatic focus and automatic exposure detectors
[0097] **48** electronic flash
[0098] **50** image processor
[0099] **52** memory card interface
[0100] **54** removable memory card
[0101] **56** RAM memory
[0102] **58** firmware memory
[0103] **62** host interface
[0104] **64** interconnection
[0105] **66** host PC
[0106] **70** color LCD image display
[0107] **90** cellular processor
[0108] **92** cellular modem
[0109] **94** antenna
[0110] **202** image compositor
[0111] **204** wide image
[0112] **206** telephoto image
[0113] **208** composite image
[0114] **210** zoom amount
[0115] **212** image registration determiner
[0116] **214** image resampler
[0117] **220** wide video images
[0118] **222** telephoto video images

[0119] **224** composite video
[0120] **600** cell phone
[0121] **602** microphone
[0122] **604** speaker
[0123] **606** keypad
[0124] **608** (LCD) display
[0125] **610** cellular image capture assembly
[0126] **612** first fixed focal length lens
[0127] **614** first image sensor
[0128] **616** second fixed focal length lens
[0129] **618** second image sensor
[0130] **620** substrate
[0131] **622** IR cut filter
[0132] **624** electronic components
[0133] **626** flex connector
[0134] **628** auto focus subsystem
[0135] **630** z dimension

1. A method of producing a digital image having portions with different resolutions comprising:

(a) simultaneously capturing first and second digital images of the same scene wherein the first digital image is of a larger portion of the scene than the second digital image wherein the second digital image has a higher resolution than the resolution in the first digital image corresponding to the second digital image; and

(b) combining at least a portion of the second digital image into the corresponding portion of the first digital image to thereby provide a digital image having portions with different resolutions.

2. The method of claim **1** further including providing an image capture device having two lens systems and two image sensors, each lens system corresponding to a different one of the image sensors.

3. The method of claim **2** wherein each lens system includes at least one fixed focal length lens.

4. The method of claim **2** wherein one of the lens systems is an adjustable focal lens system.

5. A method for operating an image capture device to produce a digital image having portions with different resolutions comprising:

(a) providing an image capture device having an image processor, two lens systems, and two image sensors, each lens system corresponding to a different one of the lens systems:

(b) operating the image capture device to simultaneously capture first and second digital images of the same scene wherein the first digital image is of a larger portion of the scene than the second digital image wherein the second digital image has a higher resolution than the resolution in the first digital image corresponding to the second digital image; and

(c) using the image processor to stitch at least a portion of the second digital image into a corresponding portion of the first digital image providing a composite digital image having portions with different resolutions.

6. The method of claim **5** further including adjusting the zoom lens prior to image capture.

7. The method of claim **5** wherein each lens system includes at least one fixed focal length lens.

8. The method of claim **5** wherein one of the lens systems is an adjustable focal lens system.

9. The method of claim **5** wherein the two lens systems have a common optical axis.

10. The method of claim **5** wherein element (c) further includes using a zoom amount to stitch the first digital image and the second digital image.

11. The method of claim **5** wherein the composite digital image is a series of video images wherein each digital image in the video has different resolutions.

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